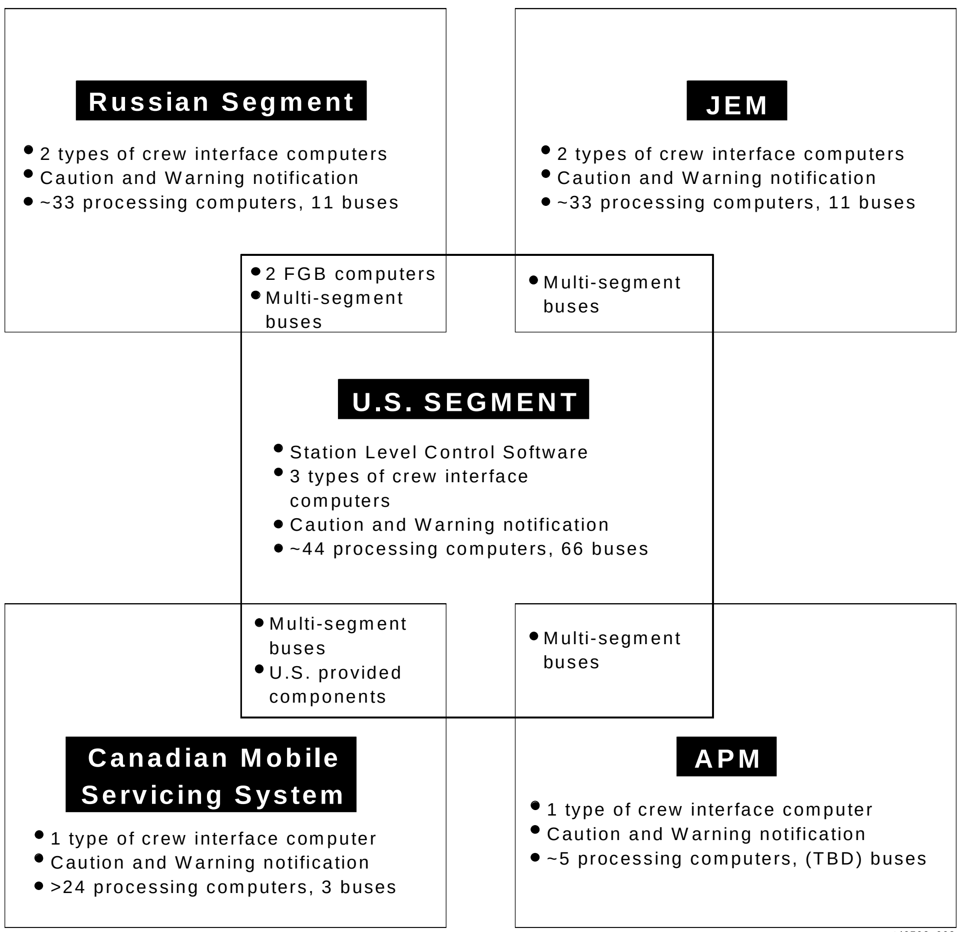
Section 2
Command and Data Handling Overview

2.1 Introduction

There are a total of over 100 different computers on the Station at assembly complete which are primarily used to collect data from onboard systems and payloads; process that data with various types of software; and distribute commands to the right equipment. Figure 2-1 identifies the various partner systems that comprise the overall Station computer system: the U.S. Command and Data Handling (CDH) System, the Russian Onboard Complex Control System (OCCS), the Canadian Computer System, the Japanese Data Management System and the European Data Management System. The Canadian Computer System is used exclusively for the robotics system and is discussed primarily in the robotics section. The remaining computer systems are described in this section.



Notes:
1. Crew interface computers exclude computers used for payload operations and dedicated hardware switch panels.
2. The multisegment buses connect to various computer ports throughout the Station. This allows for some crew interface computers to be used in multiple computer systems.
3. Processing computers do not include keyboards or monitors.

Figure 2-1. Station computer systems at assembly complete

There are five major points to address from Figure 2-1 that form the basis for the rest of this section.

a. The U.S. CDH system has a unique aspect to its computer system because it provides "Station level control" software. This software keeps all parts of the Station vehicle operationally integrated.

b. There are a variety of crew interface computers throughout the Station. The crew interface computers have some common characteristics, but also have some aspects unique to each partner system.

c. All Station computer systems have Caution and Warning (C&W) capabilities. These capabilities also have some common and some unique characteristics throughout the partner systems.

d. All partners provide numerous processing computers and data buses located within their partner segment. There are two exceptions to this. First, two of the computers located in the Functional Cargo Block (FGB) used to process FGB data and commands have hardware provided by the U.S. However, the software within them is Russian developed and MCC-M is operationally responsible for them. Second, several portions of the Canadian Computer System, such as the robotic workstation, are provided by the U.S.

e. Multisegment data buses exist between partner computer systems. These buses ensure that the Station level control software, the crew interface computer inputs, the C&W information, and the partner processing computers and associated data buses are functioning as an integrated system throughout Station.

2.2 Objectives

Upon completion of this section, you should be able to

- Describe the seven International Space Station (ISS) modes
- Identify the purpose of the seven different types of crew interface computers on the Station at 8A
- Explain how the four classes of C&W alarms are indicated on Station
- Describe the U.S. CDH-tiered architecture
- Describe the naming convention used for Multiplexer/Demultiplexers (MDMs) and 1553 buses
- Explain operational considerations associated with CDH software telemetry collection, command response, time synchronization, and automated Fault Detection, Isolation, and Recovery (FDIR)
- Relate the Russian OCCS architecture to the U.S. CDH architecture
- Describe the interfaces between the U.S. and Russian computer systems

2.3 Station Level Control Software (Modes)

The ISS supports a variety of operations including microgravity, reboost, and proximity operations. The configuration of the Station systems and the allowable activities vary according to the operation. For example, it would be unwise to fire propulsion jets while microgravity payload operations are in progress. To aid crews and controllers in configuring the systems and preventing unwanted activities, the ISS has Station-level control software divided into seven Station modes. Table 2-1 identifies the Station mode, characteristics, and example system configuration changes when transitioning into that mode. ***Some of these changes are done automatically by the software and others are performed by the operator.***

Table 2-1. Station modes

Station mode	Characteristics	Example system configuration changes
Standard	Supports all nominal housekeeping, internal maintenance, and nonmicrogravity payload operations Entered automatically by the software from microgravity mode, or manually by the crew or ground Serves as gateway between microgravity, reboost, proximity operations, and external operations modes	• Transition International Partner (IP) segments to standard mode • Power on and activate payload computer • Shutdown Extravehicular Activity (EVA) operation support equipment • Shutdown Active Rack Isolation System (ARIS) • Shutdown Mobile Transporter (MT)
Microgravity*	Supports all microgravity payload operations Entered manually by crew or ground	• Transition IP segments to microgravity mode • Shutdown Space-to-space subsystem radio • Startup ARIS • Configure Guidance, Navigation and Control (GNC) to Control Moment Gyro (CMG) attitude control mode
Reboost *	Supports Station orbit reboost operations Entered manually by crew or ground	• Transition IP segments to reboost mode • Configure GNC to CMG/Reaction Control System (RCS) assist attitude control mode
Proximity Operations *	Supports all nominal rendezvous and departure operations for the orbiter, Soyuz, Progress-M and all other external vehicles Entered manually by the crew, ground or external vehicle	• Transition IP segments to proximity ops mode • Configure space-to-space subsystem radio to orbiter mode • Configure GNC to CMG/RCS assist attitude control mode
External Operations *	Supports all external assembly and maintenance operations involving EVAs and external robotics Entered manually by the crew or ground	• Transition IP segments to external ops mode • Configure space-to-space subsystem radio to EVA mode • Configure GNC to CMG/RCS assist attitude control mode
Survival *	Supports long-term Station operations in the presence of a major failure and lack of operator control Entered manually by crew, ground, or external vehicle OR automatically upon detection of a complete failure of critical Station functions.	• Transition IP segments to survival mode • Shutdown user payload support equipment • Shutdown ARIS • Shutdown EVA operation support equipment
Assured Safe Crew Return (ASCR) *	Supports emergency separation and departure of the Soyuz vehicles for an unplanned crew return. Entered manually by crew, ground or external vehicle	• Transition IP segments to ASCR mode • Shutdown user payload support equipment • Shutdown ARIS • Shutdown EVA operation support equipment • Command GNC to attitude selected for Soyuz departure

*Mode also supports all housekeeping, internal maintenance and non-microgravity payload operations that are compatible with the mode.

Station modes are very similar to major modes used on the space shuttle. The Station is only in one mode at a time; the mode reflects a major operational activity, and the Station must be commanded to transition to another mode. ***All mode transitions can be manually commanded***

by the onboard crew or ground. Transitions to proximity operations, survival, or ASCR can also be commanded from an external vehicle. The Station level control software can automatically transition to only two modes: to survival from any mode, and to standard from microgravity mode only. Notice from Table 2-1 that when a transition to a mode occurs, the software always automatically issues commands to the IP segments to transition to the required mode. This reflects the "multisegment" nature of this software. Also notice that the transition between modes, from microgravity to proximity operations for example, must always transition through the standard mode, except for survival and ASCR modes. Figure 2-2 depicts a typical mission cycle of 50 days that includes a shuttle arrival and departure. Notice that standard mode is located between all other modes. The frequency of mode transitions could be as high as several in a couple of days (proximity operations) or as low as once per month (sustained microgravity). ***In general, mode transitions should take less than 10-15 minutes to complete. Mode transitions are always initiated before the new operation begins and always finish with a message to the operator when the transition is complete.***

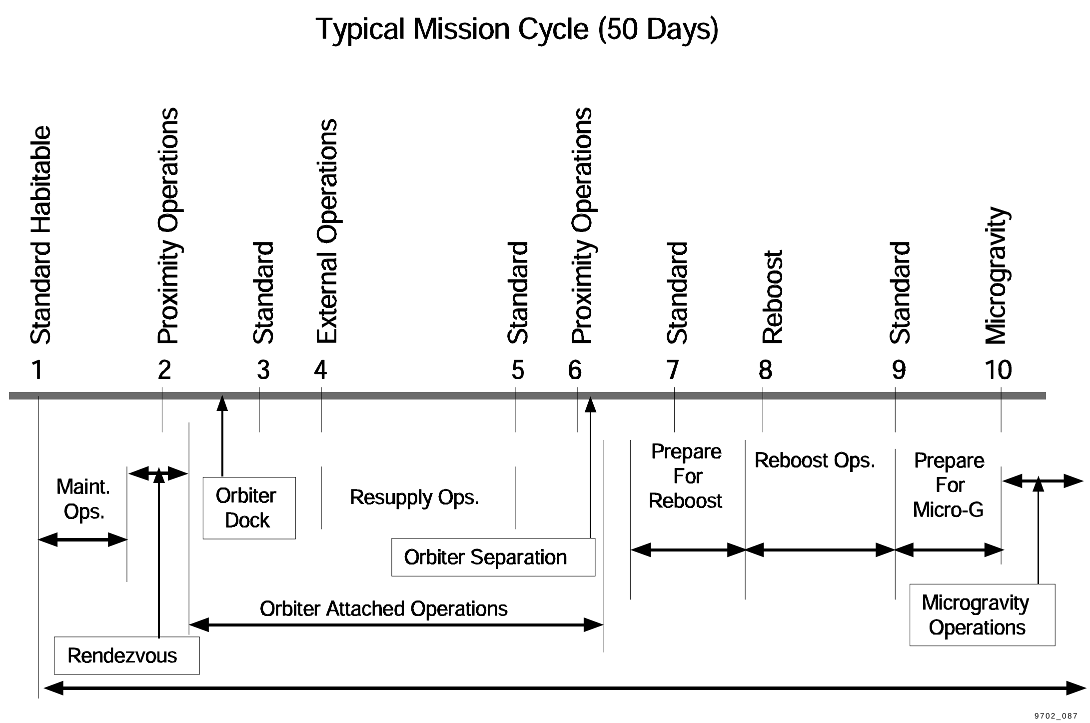


Figure 2-2. Station modes

Because of the implied criticality of survival mode, the Station-level control software monitors the vehicle's condition and automatically transitions to survival mode under specific conditions. Conditions that trigger the transition primarily involve complex combinations of repeated voltage limit violations of Battery Charge Discharge Units (BCDU) in the U.S. Electrical Power System (EPS) and various losses of the U.S. Internal Thermal Control System (ITCS). ***The crew or the ground can disable or enable the automatic transition to survival mode capability.***

In summary, the ISS has multisegment Station-level control software that aids in configuring systems for certain ISS operations. These operations are divided into seven modes: standard, microgravity, reboost, proximity operations, external operations, survival, and ASCR. Mode transitions occur regularly and can all be executed manually. Transitions to standard mode

from microgravity mode and to survival mode from any mode can also occur automatically by the software.

2.4 Crew Interface Computers

Since Station-level control software is part of the U.S. CDH system, the crew can command a mode change only through the U.S. crew interface computer used to control the vehicle, called the Portable Computer System (PCS). However, there are a total of seven different types of crew interface computers on the Station at 8A. The Station has significantly fewer hardware switches used to control systems than past space vehicles typically did. Instead, ***the vehicle is controlled with "software switches" by commanding directly to graphical displays on the crew interface computers.*** Thus, the crew interface computers have replaced the typical cockpit environment and are crucial to the successful operation of the Station. ***Many of the crew interface computers are commercial-off-the-shelf (COTS) laptop computers which plug into fixed ports connected to computer system buses.*** Table 2-2 lists each type of crew interface, its purpose, a description of the hardware/software used, and 8A location. Because the laptops are easily and often moved through the Station, location in Table 2-2 refers to the port location when the crew interface is a laptop.

Table 2-2. Crew interface computers at 8A

Type of crew interface computer	Purpose	Hardware/software description	8A location
PCS	• Execute Station mode changes • Manage Station C&W • Command and control U.S. systems	• IBM Thinkpad 760XD laptop at 8A • Data and Power cables • Various PC cards • 6 PCSs on Station at 6A • 2 general purpose printers available in U.S. lab • Solaris UNIX operating system	PCS Ports: • 4 in lab • 2 in Service Module (SM) • 2 in FGB • 2 in airlock • 2 in orbiter
Station Support Computer (SSC)	• View U.S. and multi-segment electronic procedures • Use inventory management system • View and edit onboard short term plan • Provide standard office automation tools and other crew support software	• IBM Thinkpad 760XD laptop at 8A • Power cables • Radio Frequency (RF) PC cards • 1 SSC on Station at 6A (Note: 7 "early" SSCs are also available at 6A, but use an earlier version of the laptop - the IBM 760ED) • Windows 95 operating system • Additional Thinkpad will serve as file server for RF Local Area Network that allows SSCs to communicate to server	• A minimum of 3 RF Access Points are placed strategically throughout the modules to maximize RF coverage. • Access Points include power supply connections.
Control Post Computer (CPC)	• C&C Russian systems using combination of software and hardware switches • Manage Station C&W	1 Fixed console with interfacing laptops	SM
Russian laptop	• Command and control Russian systems • Manage Station C&W	• IBM Thinkpad 760ED • Data and power cables • Various PC cards • 1 General purpose printer for Russian segment	Russian laptop ports: • 4 in SM
Payload laptops and Payload rack computers	Command and control payloads	• TBD • Many payload laptops run independently from the computer systems; don't require port connectivity	Payload ports: • 4 U.S. payload ports and 1 NASDA port in U.S. lab • TBD ports in Russian segment
Robotic workstation	• Command and control	• 2 fixed robotic workstations include 2 Hand	Robotics ports for use with PCS:

Type of crew interface computer	Purpose	Hardware/software description	8A location
computer	robotics • Manage Station C&W	Controllers and dedicated processing computers • A PCS connects to the robotic workstation or to various robotics ports	• 2 in lab
Crew Health Care System (CHeCS) laptop	Monitor crew health	IBM Thinkpad 760XD	Crew health ports: • 6 in SM • 3 in lab

There are some common and some unique characteristics in the crew interface computer hardware and software. Notice that the IBM Thinkpad 760XD is used for the PCS, SSC, and crew health care laptop. It is also used with the robotic workstation. A picture of this computer is shown in Figure 2-3. The topological view of Station shown on the laptop screen, and repeated in a larger format in Figure 2-7, is a PCS display called the ISS Homepage. This display is similar to the desktop screen on a personal computer. ***From this display, crewmembers are able to navigate to Station systems information by selecting an element on the layout and then clicking on one of the system buttons shown on the right edge of the display. Alternately, crewmembers can access system information across several elements by clicking first on a system button. At the top of the homepage are several lines of information called the C&W header. This header provides key safety information to crewmembers.***

Figure 2-3. IBM Thinkpad 760XD

The same computer hardware is also used in the Japanese Experiment Module (JEM) and APM modules as the primary crew interface computer. However, even though the IBM Thinkpad 760XD is used by multiple partners, the software is unique to each partner. In particular, ***crew displays and navigation methods are different for each partner's crew interface computer. However, all displays are required to use the English language and metric system units. Other languages and measurement units may also be provided if desired.*** Figure 2-4 is a picture of one of the fixed crew interface computers on Station used to control systems, the Control Post Computer (CPC). The robotic workstation is another fixed workstation and is described in the robotics section.

Figure will be included in next version

Figure 2-4. Control Post Computer

An advantage to using laptops as the primary crew interface to systems is that they are easily moved and relocated throughout the Station, assuming the appropriate data and power connectivity is available. ***As shown in Table 2-2, ports for the PCS are available in all major modules. However, an added complexity is that the PCS ports typically connect to different data buses. Crewmembers must consider which bus they are connected to before executing PCS operations.*** At Assembly Complete, there are also PCS ports in the JEM and APM, and JEM/APM ports in the U.S. lab.

Another key advantage to using laptops on Station is the ease of upgrading them. Computer capabilities are rapidly increasing, and with the laptop-based design, Station will be able to incorporate new laptops fairly easily. In fact, prior to 5A, an earlier version of the IBM Thinkpad, the 760ED model, is being used on Station. The transition from the 760ED to the 760XD at 5A for the PCS specifically, makes a number of extra laptops available onboard. These are initially used to supplement the number of SSC computers as indicated in Table 2-2. More detail on the evolution of the laptops onboard Station can be found in the CDH training manual.

2.5 Caution and Warning

2.5.1 C&W Function and Classes

The C&W header part of the ISS Homepage shown in Figure 2-7 is one of the ways that crewmembers can obtain key Station safety information. Several additional methods to alert and inform crewmembers of Station conditions are provided by the C&W system. This system alerts the crew and ground of conditions that 1) endanger the safety of the crew or Station, 2) negatively impact mission success, or 3) indicate out of tolerance conditions. Events that trigger the C&W system are grouped into four classes which are common across all partner segments. The classes tie directly to the aural and illumination methods that are used to indicate the conditions. Table 2-3 identifies the C&W classes, definitions, and example events. The tone and color associated with each class is also depicted. ***Note that there are only three defined emergencies on Station: fire, loss of pressure, and toxic atmosphere.*** Also, notice that while advisories are considered one of the C&W classes, they are described as a “non-C&W item” because they are used for status and support information only.

Table 2-3. Caution and warning classes

C&W class	Definition	Example events
Class 1 - Emergency tone - repeating beeps color - red	Event that causes a life-threatening condition for the crew that requires immediate crew action	Only three defined emergencies: 1. Fire or smoke in pressurized element 2. Rapid change in cabin pressure 3. Toxic atmospheric conditions
Class 2 - Warning U.S. tone - siren Russian tone - TBD Color - red	Detected hardware or software failure which requires immediate corrective action to avoid major impact to the mission, or potential loss of Station or crew.	• Loss of the primary U.S. Guidance, Navigation & Control (GNC) Computer • Detection of high cabin pressure • Loss of CMG attitude control
Class 3 - Caution U.S. tone - constant tone	Out-of-tolerance condition that is not time critical in nature and identifies impact which, if left uncorrected, may become a Warning.	• Loss of the backup GNC Computer • Critical Failure of the S-Band Communications Baseband Signal Processor

Russian tone -TBD Color - yellow		• Failure of 1 of 4 U.S. CMGs which provide attitude control
Class 4 - Advisory	Non-C&W message which provides information about systems status and processes.	• Non-Critical Failure of S-Band Baseband Signal Processor • Trip of Remote Power Control Module (electrical switch)

2.5.2 C&W Indications

There are three methods for indicating to a crewmember that a C&W event has occurred on Station: illuminated lights on the onboard C&W panel hardware, tones from onboard audio equipment in the Communications system, and text/graphic messages on the PCS and/or Russian PCS. All three methods are used to indicate emergencies, warnings and cautions. Only the text/graphic message is used for advisories.

The U.S., Japanese and European modules use the same U.S. designed and built C&W panels shown in Figure 2-5. The C&W panel consists of five pushbutton lights: one for each of the emergencies, one for warning and one for caution. There is also a test button to ensure the lights are still functioning. The emergency and warning buttons are red, and the caution button is yellow. Figure 2-6 shows the Russian C&W Panel which is completely different from the Mir C&W panel. The panel consists of lights which indicate the type of C&W event and the effected module, and buttons for manual event initiation and silencing events.

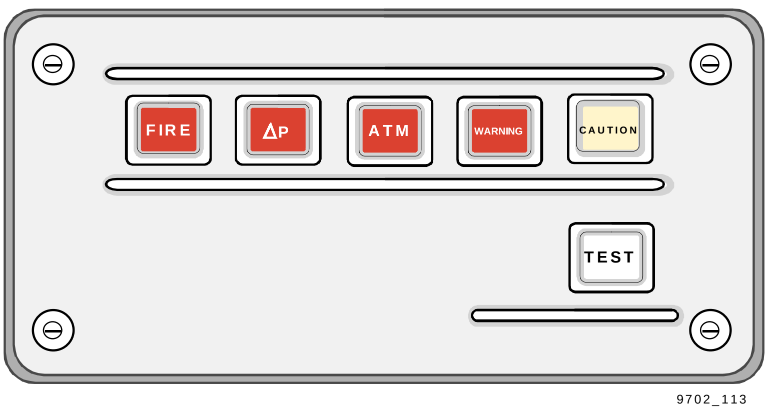


Figure 2-5. U.S. segment caution and warning panel

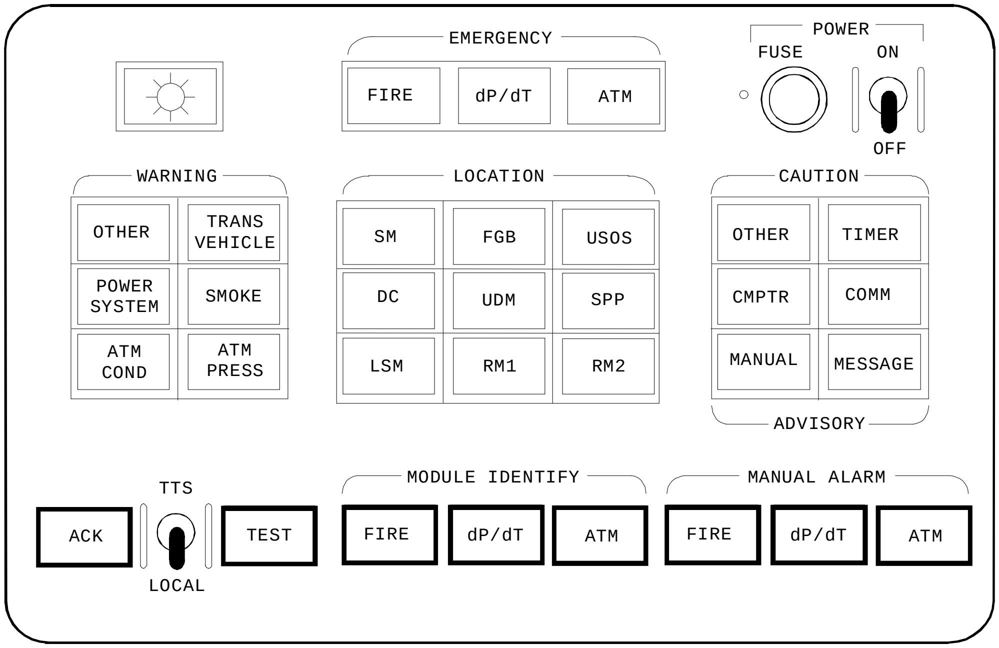


Figure 2-6. Russian segment caution and warning panel

There are different C&W tones on Station that correspond to the C&W classes. All partner segments use the same repeating beep tone to indicate any of the three emergencies. ***The U.S. segment, JEM and APM use a siren for warnings and a constant tone for cautions. The Russian segment uses a TBD for warnings and a TBD for cautions. While the C&W panels illuminate the event, they do not provide the associated tone. Tones in the U.S. segment, the JEM and the APM are annunciated by the communication system's Audio Terminal Unit (ATU), which is similar to an intercom system.*** Like the C&W panel, the U.S., Japanese and European modules contain the same U.S. designed and built ATUs. The Russian modules annunciate tones using the Telephone-Telegraph Communication Subsystem (TTCS). There are two different TTCS Audio Control Units (ACUs) used in the Russian segment. The 95-1 unit used in the SM is identical to that used on Mir. However, a newer model, 95-5, is used in the FGB. Both the ATU and the ACU are discussed in more detail in the Communications and Tracking (C&T) section.

PCSs are an essential information source for C&W. Current operational concepts require at least one operating PCS in each major Station module to allow management of detailed C&W information. The PCS provides several C&W displays, including the C&W header mentioned earlier. Notice from Figure 2-7 that the C&W Header is very similar to the U.S. C&W panel, but also includes an Event Message display field and counters for in-alarm warnings and cautions. The C&W header is shown at the top of many different displays, not just the ISS Homepage, to ensure crewmembers quick access to the data. Additionally, the ISS Homepage highlights the effected element and system either red or yellow based on the class of the event. There are two more PCS displays used to manage the C&W system: the C&W Summary display and the C&W Log. These displays are covered in the CDH Training Manual. While the PCS displays provide detailed C&W information to crewmembers, ***the C&W tones are not annunciated at the PCS.*** Russian laptop C&W displays are TBD.

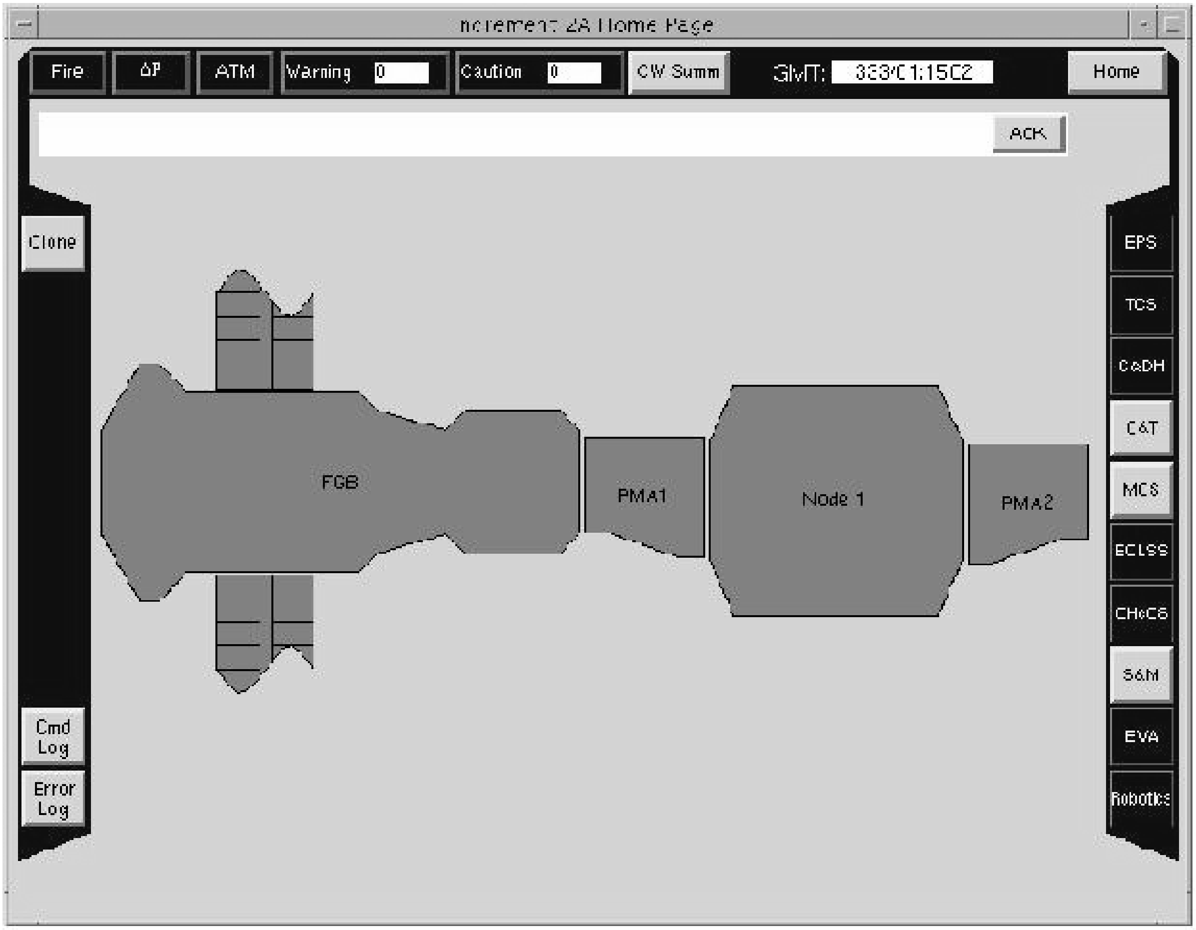


Figure 2-7. C&W header and ISS home page

Because there are three simultaneous, but separate, indications of C&W information, it is important to depict the location of each source within the Station. Figure 2-8 shows the module locations of C&W panels, ATUs/ACUs, and PCS/Russian laptop ports. Notice that there are no ATUs or C&W panels in Node 1.

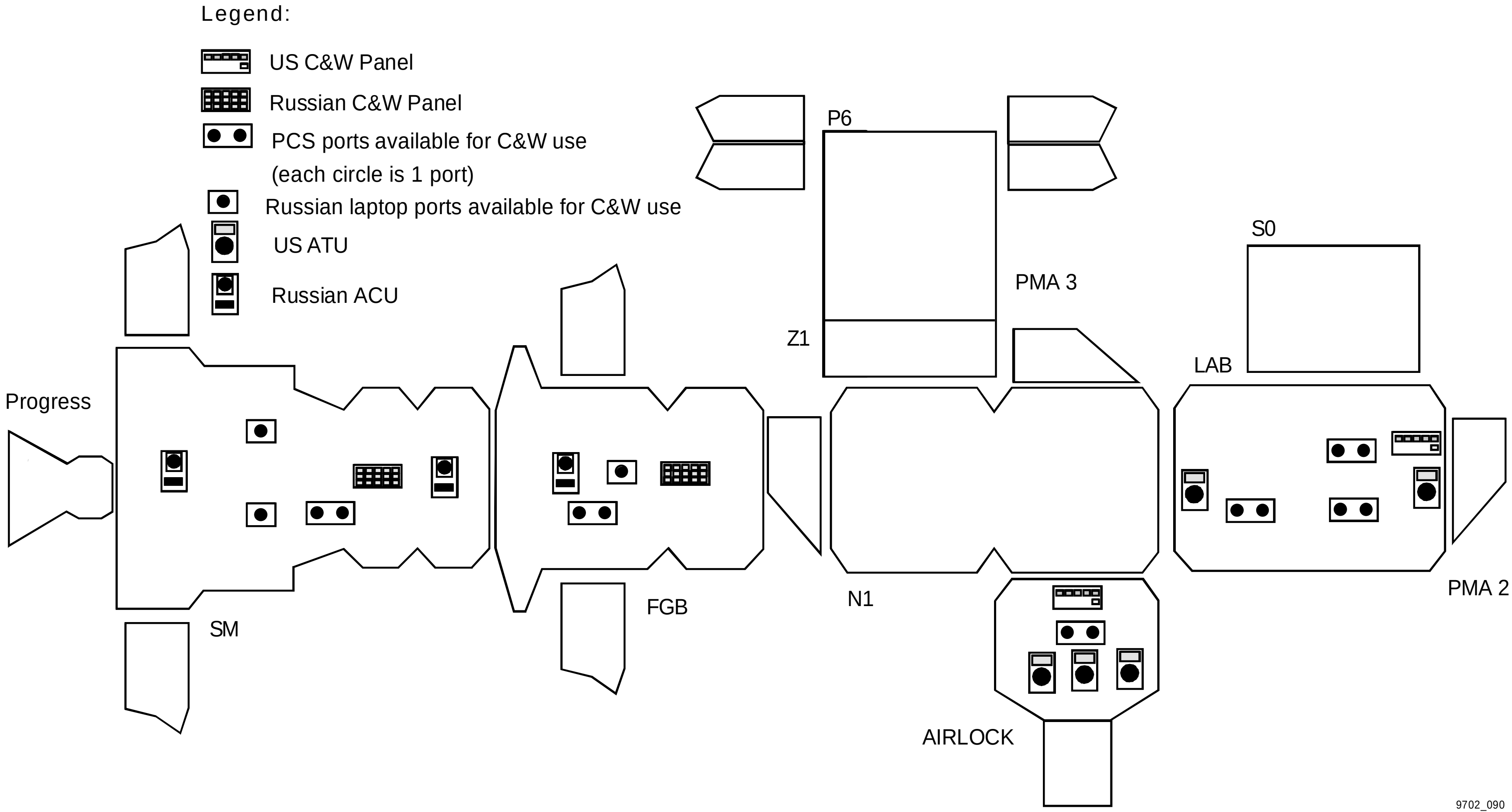


Figure 2-8. Module locations of C&W panels, ports for C&W data and ATU/ACUs

2.5.3 C&W Exchange Between Partner Modules and the Orbiter

While there are three methods for indicating C&W throughout Station, there are limitations on what C&W information is available between the U.S. and Russian segments. As stated in Section X.2, the partner computer systems are interconnected by multisegment databuses. These buses are used to share some C&W information throughout the Station. For the U.S. and Russian segments specifically, ***the Russian computer system and the U.S. computer system send electronic C&W information across the multisegment buses, but the lights and tones are generated by each segment independently. The information exchanged between segments includes only the notification of an in-alarm event, its class and identification number.*** The same information is passed between the U.S. computer system and the JEM and APM systems.

Also, recall from Table 2-2 that two PCS ports are available in the orbiter. Therefore, ***Station C&W information can be viewed and controlled from the orbiter PCSs when docked.*** The information exchange between the Station and the orbiter is similar to that between the U.S. segment and the Russian segment. ***The orbiter receives a subset of the electronic Station C&W information and generates the lights and tones independently, according to its own C&W standards. However, the Station does not receive or annunciate any orbiter C&W events.***

2.5.4 Caution and Warning Assembly

Prior to lab activation on Flight 5A, all C&W lights and tones are generated by the Russian segment since there are no C&W panels or ATUs in Node 1. However, the U.S. PCS in the Russian segment does provide C&W display information on all U.S. monitored telemetry.

2.6 Processing Computers and Data Buses

2.6.1 U.S. Command and Data Handling System

2.6.1.1 CDH-Tiered Architecture

The U.S. crew interface computers receive their telemetry from and impart their commands to the U.S. CDH computers. At 8A, the U.S. CDH system consists of 25 processing computers interconnected by data buses that collect, process, and distribute both data and commands. The computers consist only of the processing box, they have no associated keyboards or monitors. The CDH computers exchange data and commands in a hierarchical functional structure referred to as tiers. This is implemented in the U.S. CDH system by grouping the computers and associated data buses into three tiers called the control tier, the local tier, and the user tier. The tiers are arranged conceptually as depicted in Figure 2-9. To help recall the tier names, note that they are in alphabetical order. The figure also shows that the highest tier, the control tier, has the fewest number of computers, while the lowest tier, the user tier, has the greatest amount of computers.

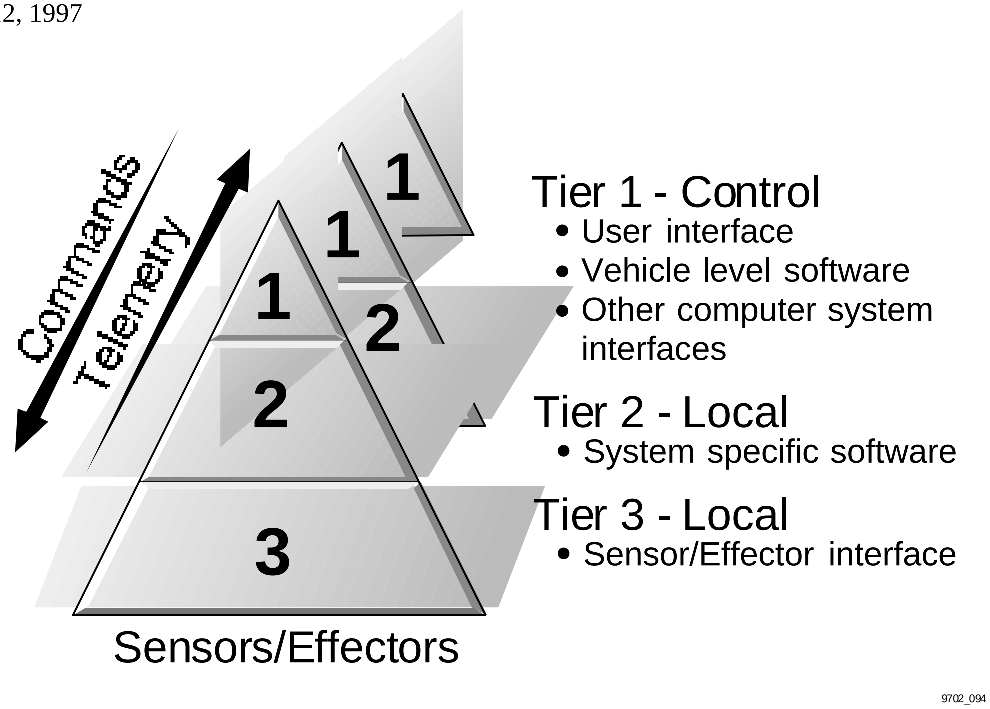


Figure 2-9. Conceptual view of CDH architecture

All processing computers in the CDH system, regardless of tier, perform multiplexing and demultiplexing of data. However, each tier typically has another unique purpose. The primary purpose of the control tier, as the name implies, is to provide the interface for the crew and the controllers. They interface with the CDH computers via the PCS and MCC respectively through Tier 1 only. Tier 1 provides two additional functions: first, it processes vehicle level software such as C&W and Station modes, second, it provides the interface to the IP computer systems and the orbiter. Tier 1 computers are connected via data buses to the Tier 2 computers. The primary purpose of Tier 2 is to execute system-specific application software. Examples of this Tier 2 application software include GNC software that converts CMG gimbal angles and gimbal rates into momentum states or Environmental Control Life Support System (ECLSS) software that monitors CO_2 levels in the Station's atmosphere and controls air flow to the Carbon Dioxide Removal Assembly (CDRA) by positioning the Process Air Valve (PAV). Tier 2 computers are connected via data buses to the Tier 3 computers. The main purpose of the Tier 3 computers is to provide input/output processing to the thousands of sensors and effectors on the Station. Examples of sensors and effectors that Tier 3 computers interface to include temperature sensors, pressure sensors, rack flow control assemblies, and remote power controllers. The tier 3 computers complete such processing as converting the sensor analog data to digital data and monitoring the condition of the attached hardware. Thus, Tiers 1,2, and 3 provide the crew/controller interface, execution of system application software, and sensor/effector interface respectively. There are exceptions to this, but generally this tiered functionality applies throughout the CDH System.

A key operational consideration to this tiered architecture is the flow of commands and telemetry. As depicted in Figure A, for commands to reach an effector attached to a Tier 3 computer, they must start at Tier 1, pass through Tier 2 and on to Tier 3. Conversely, data from sensors attached to Tier 3 computers must go from Tier 3 to Tier 2 to Tier 1. ***Crews and***

controllers are only able to access data that has been passed all the way to the Tier 1 computers.

While this tiered architecture may seem overly rigid, there are several reasons for this design. First, to decrease complexity and increase safety, designers wanted one user (crew/controller) interface to the system. Secondly, each computer is limited in the amount of buses and devices it can control. Generally, a computer can control a maximum of 10 buses, and each bus can host a maximum of 32 devices. Because there are thousands of Station sensors and effectors and over 30,000 U.S. telemetry points, the processing had to be “distributed” among a variety of computers. This is why the CDH system is also referred to as a “distributed” system - there are many interconnected computers which all process information.

Another key aspect of the tiered architecture is the redundancy scheme. ***Generally, the Tier 1 computers are two fault tolerant (three identical computers), the Tier 2 computers are one fault tolerant (two identical computers), and the Tier 3 computers are zero fault tolerant (only one computer with that specific set of software). However, some redundancy in Tier 3 computers is obtained by a complex allocation of software between computers.*** For example, redundant strings of sensors and effectors may be tied to different Tier 3 computers. Additionally, in some cases, designers have placed software providing redundant functions in different Tier 3 computers. A specific instance of this redundancy is seen in the ITCS. The ITCS has two separate internal thermal loops, the low temperature loop and the moderate temperature loop. They are not redundant loops, but can be interconnected to account for the loss of a pump on either loop. The software controlling the low temperature loop is in one Tier 3 MDM, and the software controlling the moderate temperature loop is in another Tier 3 MDM. The MDMs are not identical, but between the two MDMs, some redundancy in the Thermal Control System (TCS) and CDH System is achieved. For more details on the implementation of this complex Tier 3 redundancy, see Section 2 and the “software residency” tables in the appendix of the CDH training manual.

Thus, the CDH-tiered architecture has three tiers: control, local, and user with each tier generally having a different purpose. Commands and telemetry must flow sequentially through the tiers and users only directly interface with Tier 1 computers. The redundancy scheme for CDH is generally associated with the tiers; Tier 1 has the greatest redundancy while Tier 3 has the least redundancy.

2.6.1.2 CDH Hardware

In the previous section, the overall philosophy of a tiered architecture was described. Within the actual CDH design, the three tiers are composed of various processing computers and buses. A functional drawing of the tiered architecture is shown in Figure 2-10. The rounded-corner rectangular boxes in Figure 2-10 depict the Russian computers that directly interface to the U.S. CDH System. There are three major types of U.S. hardware depicted in this drawing: the U.S. processing computers that control Station systems (referred to as MDMs - Multiplexers/ Demultiplexers), the associated buses, and the payload network components.

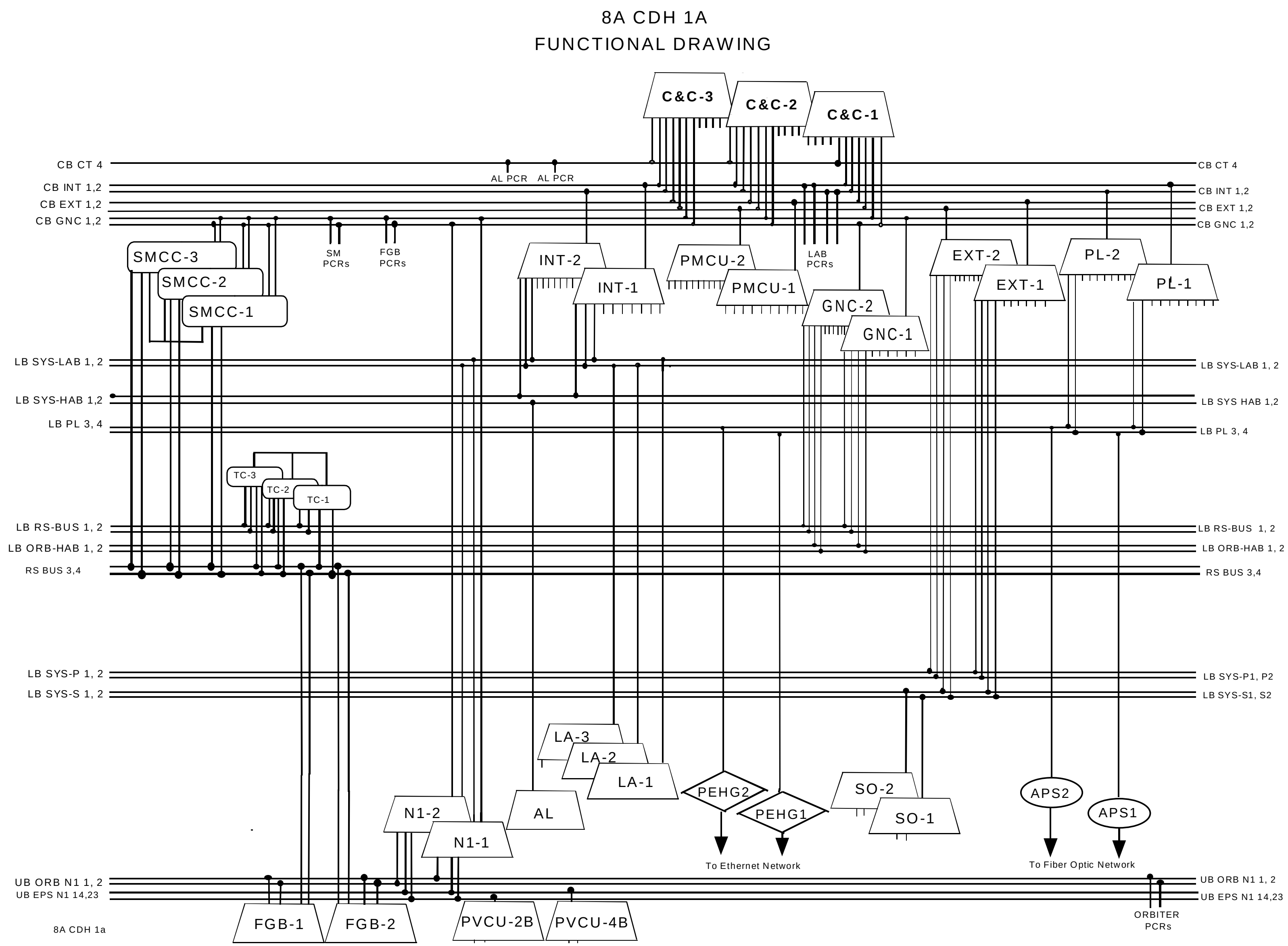


Figure 2-10. Functional drawing of CDH at 5A

Multiplexers/Demultiplexers

The trapezoidal boxes in Figure 2-10 represent U.S. processing computers that control Station systems and are called Multiplexers/Demultiplexers (MDMs). However, as described above, these computers do not just complete multiplexing and demultiplexing tasks - they run application software and process information.

Note that the Station MDMs are significantly different from shuttle MDMs. Shuttle MDMs are true MDMs while Station MDMs are a combination of a MDM and a computer.

Looking at Figure 2-10 in more detail, notice there are three identical Tier 1 MDMs, called the Command and Control (C&C) MDMs. The nomenclature for MDMs identifies the primary function of the MDM followed by an indicator for the instance of the MDM. For example: C&C-2 or C&C-3 are redundant C&C computers to the C&C-1 MDM. ***One of the C&C MDMs is fully operational, while a second is a "warm" backup (powered on and processing data but not commanding equipment) and the third is a "cold" backup (powered off).*** There are five pairs of Tier 2 MDMs; each MDM in the pair is identical to the other MDM. ***Typically, one MDM is operational and the second of the pair is powered off. However, the redundant GNC MDM is a warm backup.*** There are twelve Tier 3 MDMs. None of them are exactly alike, but MDMs performing similar functions are labeled similarly. For example: LA-1, LA-2, and LA-3. All Tier 3 MDMs are nominally powered on and operational. Note that the LA-1 and LA-2 MDMs are the MDMs which contain the low temperature and moderate temperature loop software described previously.

Figure 2-11 is a picture of a typical MDM. From the figure you can see that MDMs contain processing cards that slide in and out horizontally from the box. All the chips in an MDM are located on the cards; no chips are located on the chassis. This is similar to newer commercial personal computers and allows for easier repair and replacement of parts. All cards connect into the back of the MDM which is called the "backplane". MDMs come in three sizes based on the maximum number of cards that can be put in the MDM. The available sizes are 4, 10, and 16. The main processing card for the MDM, called the Input/Output Controller Unit (IOCU), is based on an Intel 80386SX. While a 80386 chip may seem limited in capability, this chip was selected because it sufficiently performs required processing, uses less power than newer chips, generates less heat, and fits the space allocated for it on the IOCU card (newer chips have a different shape). Other cards within MDMs include Serial Parallel Digital 1553B (SPD-1553B) cards to control bus communication, various Input/Output (I/O) cards that interface directly with sensors and effectors, and power supply cards. Some MDMs are "enhanced" with a math coprocessor, extra Random Access Memory (RAM), a larger power supply, and can also have a hard drive called a Mass Storage Device (MSD). The MDM in Figure 2-11 is considered an Enhanced MDM because of these additions, and its main processing card is called an Enhanced Input/Output Control Unit (EIOCU). Cards within an MDM are selected and located within the chassis based on the specific needs of that MDM. Even though the computers are generically referred to as MDMs, MDMs typically have different internal hardware card configurations.

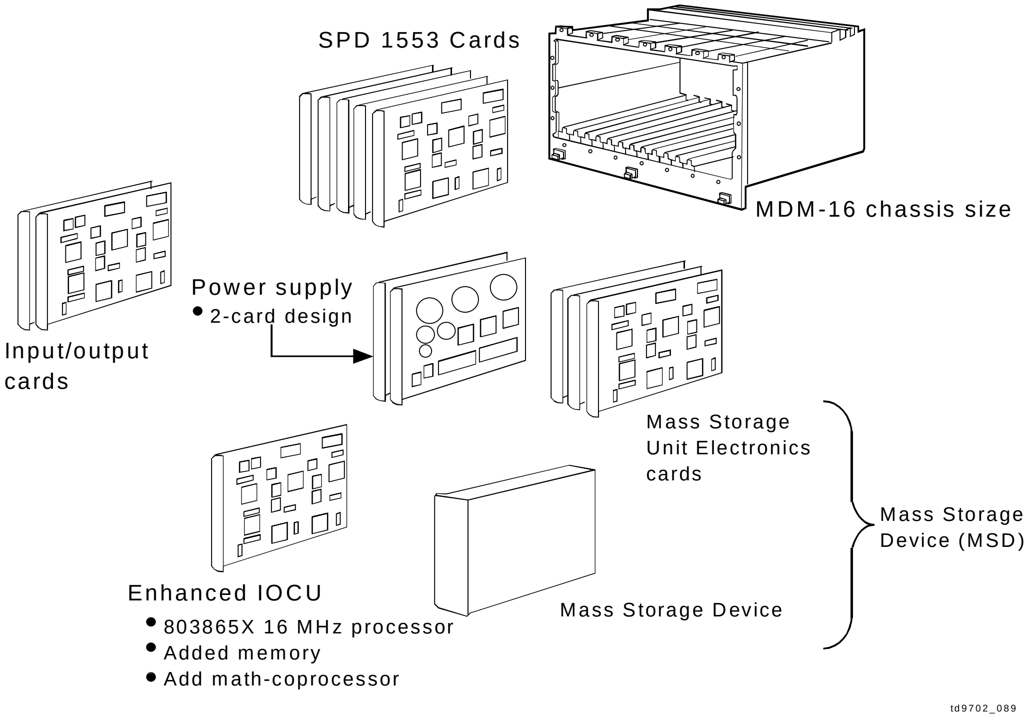


Figure 2-11. Typical CDH MDM

A key operational consideration relative to MDMs is the anticipated failure rate. Due to the high anticipated amount of radiation hits to MDMs, the current estimate is that 19 MDMs/year at Assembly Complete will have hard failures requiring maintenance. To address this, cards within the MDM are identified as Orbital Replaceable Units (ORUs) and are manifested as spares. Card changeout is an approved maintenance task and crews are expected to changeout the cards on orbit. Nearly half of these expected failures are for MDMs located outside the Station. Therefore, maintenance on these MDMs requires an on-orbit spare available for the EVA or an EVA to bring the boxes inside the Station and an EVA to return them to their original location.

Figure 2-12 provides a spatial drawing of the U.S. CDH system at 8A. Notice that in a spatial drawing the tier of the MDM is not clear. However, the MDMs still exchange data and commands in the hierarchical fashion even though their physical layout does not imply this. While the MDM’s tier cannot be identified, this drawing does show which MDMs are inside or outside the habitable volumes. Specifically, the Node 1 MDMs (N1-1 and N1-2), the external MDMs (EXT-1, EXT-2), the S0 Truss MDMs (S0-1, S0-2) and the Photovoltaic Controller Unit MDMs (PVCU-1, PVCU-2) are all located outside the habitable volume. The cards are the same regardless of whether an MDM is located inside or outside. Additionally, MDMs both inside and outside the habitable volume are designed to slowly leak pressure to equalize with their environment. This allows for equalization of the MDM when it is moved into or out of the habitable volume. The MDM also has the capability to be manually equalized by an equalization valve. The chassis is different for outside MDMs due to the need to protect the computer from the radiation and debris environment of space.

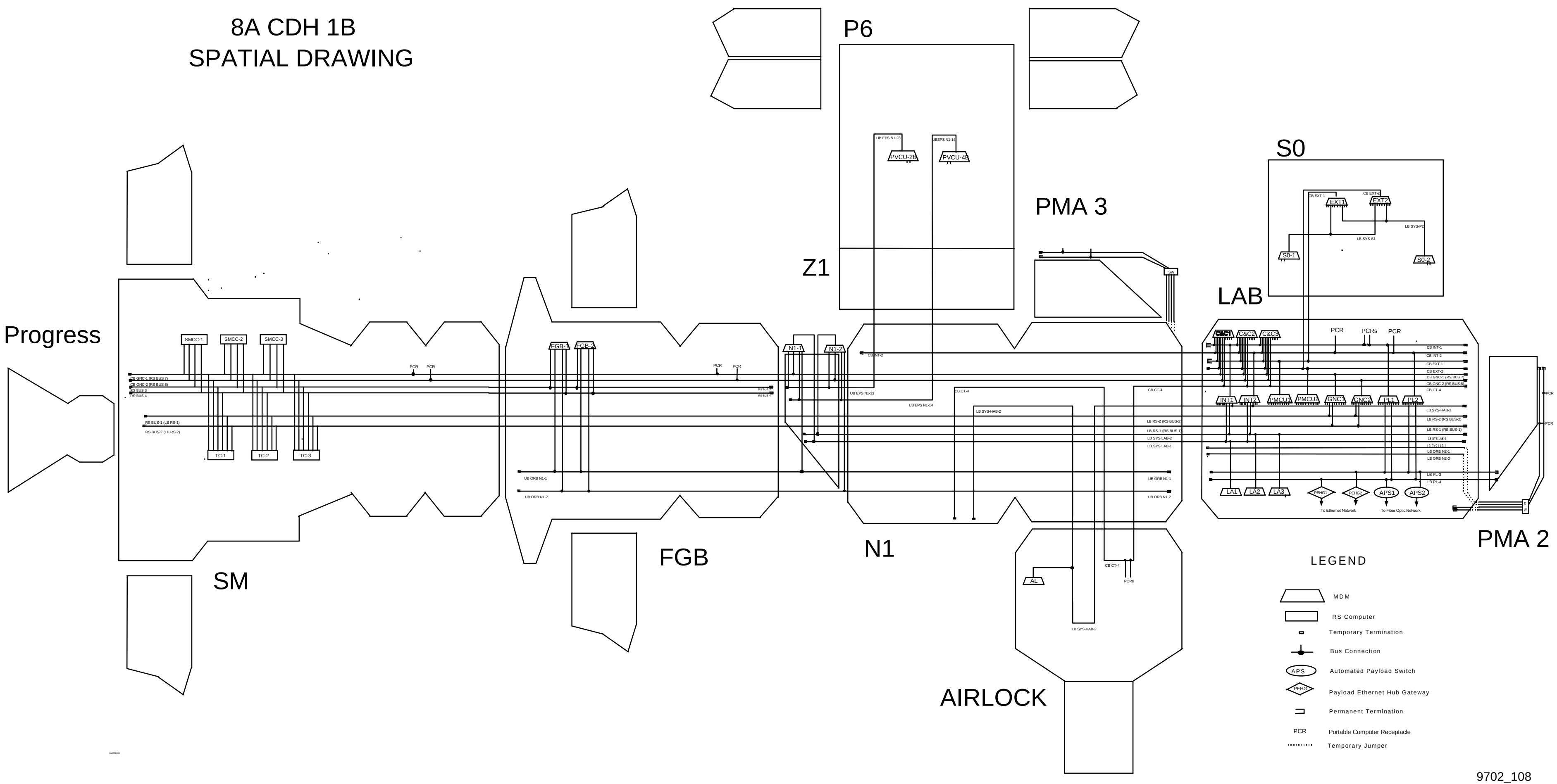
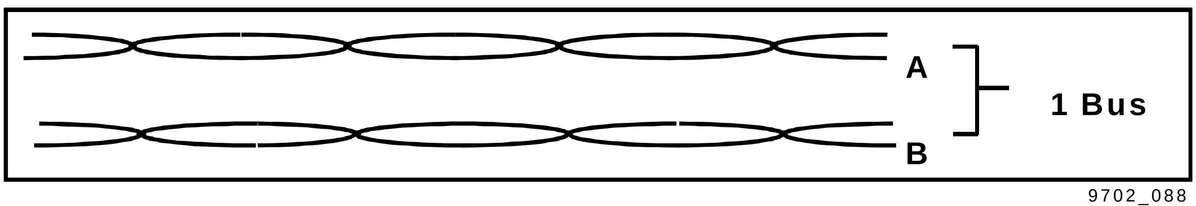


Figure 2-12. Spatial drawing of U.S. CDH at 8A

1553B Buses

The MDMs exchange data and commands between themselves via 1553B buses. These are shown in Figure 2-10 as vertical and horizontal lines. They are referred to as 1553B buses because they adhere to the bus protocol established in the Military Standard Number 1553B, Notice 2. While Figure 2-10 only shows the buses used between MDMs and other key computer system components, 1553B buses are also used on Station for communication between a CDH MDM and "smart" components in other, non CDH systems. These are depicted as bus "stubs" on the drawing. Smart components are those which have the ability to process their own information, such as firmware controllers. An example of this type of communication is the 1553B bus between the CDH LA-1 MDM and the ECLSS CDRA. For full drawings of these buses see the CDH Training Manual Appendices.

A 1553B bus consists of two twisted, shielded pairs of copper wires. Figure 2-13 depicts the difference between a Station bus and a channel; these terms are often confused. (Unfortunately, industry bus/channel terminology is exactly opposite of Station terminology). For Station, each 1553B bus consists of two channels, each channel consists of a pair of copper wires. ***The two channels provide redundancy, but only one channel is active at a time. If one channel fails, the other is available to take over communications. Channel changeover is supposed to occur with minimal impact to operations.*** Typically, the two channels of a bus are physically routed separately within a module to enhance redundancy. For example, Channel A is in one standoff, Channel B is in another. However, they are routed together through the bulkhead.



A and B are channels.
Each channel has two twisted, shielded, copper wires.
Both channels make one bus.

Figure 2-13. Bus versus channel

Each channel can communicate in both directions to send commands and receive telemetry. However, communication in both directions simultaneously creates data "collisions" on the bus resulting in invalid data. Therefore, communication occurs in one direction at a time, and it must be precisely timed to prevent collisions. This type of bus structure is called "half-duplex". The speed of the bus is quite slow, 1 Megabit/second (as compared to fiber optic networks which operate at approximately 100 Megabits/second), but it follows the Military Standard 1553B protocol. Although speed is sacrificed by using this protocol, there are several positive reasons for using the 1553B bus. Specifically, the 1553B is well-proven in space. Additionally, it has significant built-in redundancy capabilities that make it a good choice for space applications. More detail on the specifics of the 1553B protocol can be found in the Appendices of the CDH training manual.

The bus naming convention used in the CDH system and represented in Figures 2-10 and 2-12 is as follows: there are three parts to the bus name; the first part indicates the tier of the bus, CB for control bus (Tier 1), LB for local bus (Tier 2), and UB for user bus (Tier 3). This is followed by the connectivity below it, such as INT for the internal MDM or EPS for electrical components. The final part of the bus name indicates the number of the bus if there are multiple buses. Therefore, examples of bus names are:

- CB GNC-1 is control bus number 1 connected to the GNC MDM
- LB PL-3 is local bus number 3 connected to the payload MDM

Payload Network Components

The payload network components include payload MDMs (PL-1, PL-2), the payload 1553 buses, the Automated Payload Switch (APS), the Payload Ethernet Hub Gateway (PEHG-1 and PEHG-2), and additional ethernet and fiber optic payload networks. These additional buses are not shown in this drawing. The payload components provide the ability to switch between the payloads and different networks. This allows for faster and more efficient data collection needed for payloads. Further drawings and details on payload component networks can be found in Section 2 of the CDH training manual.

2.6.1.3 *CDH Software*

At Assembly Complete, the U.S. segment alone has over 300,000 parameters. This compares to a total of approximately 12,000 parameters for a typical shuttle flight. Extensive telemetry was designed into the Station vehicle because of the Station's long design life and the need to complete maintenance on orbit, as well as the desire to gather as much data as possible from the long duration environment. However, managing this large volume of data requires extensive software capabilities. Note that as described in 2.6.1.1, many MDMs contain system-specific application software. This software is considered part of the system it supports, not CDH system software, and is therefore not covered here. There are four major operational points which are consequences of the CDH software design. Specifically

a. **Telemetry:** The crew has access to any data in the C&C MDM providing that there is a display item associated with it. This means the ***Station crewmembers have significantly more insight into Station systems than the shuttle crewmembers have into shuttle systems. Due to downlink bandwidth limitations after Flight 5A, crewmembers may have more access and insight to data than MCC-H controllers as well***. Unfortunately, there currently is no method for the C&C MDM to know whether the data it is holding is stagnant (not being updated by the lower tiered MDM due to a failure). ***While shuttle displays indicate General Purpose Computer (GPC) or MDM failures as missing data with an "M" by the value, Station displays are unable to indicate stagnant data because the C&C MDM has no indication. Additionally, it is important when trying to access telemetry on the PCS to know whether the PCS is connected to a Tier 1 control bus or a Tier 2 local bus. However, if the buses are operating nominally, after Flight 5A it does not matter which specific bus within the tier is connected to the PCS.***

b. **Commands:** To aid in troubleshooting across the highly distributed, complex CDH System, ***command response indications are provided to crewmembers via the PCS command display. Again, crewmembers may have greater insight than MCC-H due to bandwidth limitations. MCC-H only receives negative command information. The PCS that sent the command receives both negative command responses as well as all the positive command responses reflecting the successful progression of the command through the CDH System.***

c. **Time Synchronization:** As mentioned earlier, bus communications need to be precisely timed and "synchronized" across CDH. ***Because of the large amount of telemetry, the precise timing of the computers is used to collect data at three different rates: 10 Hz, 1 Hz and 0.1 Hz. Data is sent to the PCS displays at the fastest rate, 10 Hz. Therefore, the crewmembers may notice their data updating at different rates - particularly for the 0.1 Hz data which is only updated once every 10 seconds. To ensure correct data is available to fill PCS displays, MDM time synchronization is critical. Because of this, there are time management capabilities available to crewmembers and controllers through CDH displays.***

d. **Automated Fault Detection, Isolation and Recovery:** ***The CDH software has two major types of automated FDIR capabilities; one declares bus failures and the other declares MDM failures. Crewmembers or MCC-H can enable or disable either of these automated FDIR capabilities. Enabling and disabling FDIR software is used extensively during Station assembly operations.***

CDH Software - Telemetry

To better understand the major operational consequences above, it is necessary to describe background information on how the CDH system software works. To gather telemetry, the CDH system uses the MIL STD 1553B protocol combined with pre-defined Station input/output bus profiles. Key terms from the MIL STD 1553B protocol that are used throughout the CDH system and displays are defined below.

Table 2-4. Key terms from MIL STD 1553B protocol

MIL STD 1553B Term	MIL STD 1553B Definition
Terminal	The electronic module necessary to interface the data bus with the subsystem and the subsystem with the data bus.
Bus Controller (BC)	The terminal assigned the task of initiating information transfers on the data bus.
Remote Terminal (RT)	All terminals not operating as the BC.
Command/Response	Operation of a data bus system such that RTs receive and transmit data only when commanded to do so by the BC.
Broadcast	Operation of a data bus system such that information transmitted by the BC or a RT is addressed to more than one of the RTs connected to the data bus.

The Station CDH operates in a command/response manner. Bus Controllers control all bus traffic. Remote Terminals do not put data on the bus unless requested to do so by the Bus Controller. Within the CDH-tiered architecture, higher Tier MDMs are Bus Controllers to the lower tier Remote Terminal MDM below it. As an example, referring back to Figure 2-10, if the Tier 1 C&C-1 MDM, the Tier 2 INT-1 MDM, and the Tier 3 LA-1 MDM are all primary MDMs processing data, C&C-1 is the Bus Controller and INT-1 is the Remote Terminal on the bus connecting the two MDMs, CB INT-1. The INT-1 MDM can only send information on the bus if the C&C-1 MDM asks for it. Similarly, INT-1 is the Bus Controller and LA-1 is the Remote Terminal on the bus connecting these two MDMs, LB SYS-LAB 2. Notice that the Tier 2 INT-1 MDM is a Remote Terminal to the bus above it and a Bus Controller to the bus below it at the same time. This is accomplished through different cards within the MDM, and is common with Tier 2 MDMs.

While the above CDH example uses only MDMs, RTs can also be smart components from other systems that communicate with an MDM over a 1553 bus - such as the CDRA referenced in Section 2.6.1.1. Other examples of RTs include the PCSs, transponders in the Communications system, or CMGs in the GNC system. While RTs can be components from other systems, to be a BC, the component must be an MDM.

Therefore, BCs request data from RTs and this process repeats through the CDH system. This is how telemetry is moved up through the CDH architecture. The most recent telemetry is stored or passes through an area of memory within each MDM called the Current Value Table (CVT). When new telemetry is placed in an MDM, it overwrites the previous telemetry. A higher-tier MDM requests telemetry from the CVT of the MDMs below it and puts it in its own CVT. The highest tier CVT is that in the C&C MDM. It is from this CVT that display data and data to be downlinked is selected. However, when new data is put in a CVT, the MDM does not check whether the data is good. Also, the CVT does not monitor whether the data is missing or stagnant. Therefore, ***Station displays are unable to indicate stagnant data because the CVTs throughout the CDH system do not monitor this.***

Associated with the CVT concept is the PCS bus connectivity. As described in Section 2.4, PCSs plug into ports that are connected to one bus. However, not all ports are connected to the same bus. For example, PCS ports are available on the CB INT-1, CB EXT-2, LB PL-1, and LB CHeCS-SM buses. All control buses accessed by the PCS connect to the C&C MDMs. By design, excluding orbiter PCSs, local buses accessed by the PCS typically connect to the Payload MDMs. Because the CVT data comes from the MDM, it is accessible to all buses attached to the MDM. ***Therefore, if all buses are operating nominally, it is only important that a PCS be connected to a control bus or a local bus, not which specific control or local. However, if a bus has failed, crewmembers must identify the bus and the ports connected to it to avoid connecting to that PCR. There is currently no indication on the PCS port hardware of the bus connectivity and bus health.***

CDH Software - Commands

As previously described, RTs do not put information on the bus unless asked to do so by a BC. The PCS is an RT to the C&C MDM and certain other MDMs. Because the PCS is an RT, when the crew issues a command from the PCS, the PCS holds the command until the BC MDM polls the RT PCS for commands. The oldest command is then sent to the BC. This BC polling and PCS RT response is done at the rate of once per second, per PCS. ***Therefore, each PCS can send a maximum of one command per second.*** The C&C MDMs can handle a maximum of eight PCSs across all control buses connected to a C&C MDM.

Figure 2-14 depicts a typical command display, often referred to as a “command/details display”. ***Notice that the display includes commands, key telemetry associated with the command, and the positive and negative command responses. Only the PCS that sent the command receives the command responses.*** The positive command responses are sent from each tier when the command successfully reaches and has been validated by the MDM in that tier. Therefore, there are several positive command responses shown in Figure 2-14, corresponding to the number of MDMs the command was processed by.

Figure will be supplied in next version

Figure 2-14. Example command/details display

CDH Software - Time Synchronization

As stated above, the MDMs collect data in the CVTs at three different rates: 10 Hz, 1 Hz, and 0.1 Hz. C&C MDM CVT data is also recorded by the Zone of Exclusion (ZOE) Recorder in the Communications System. The selection of data that the RT is commanded to send at a specific time is determined by an Input/Output Bus Profile. These profiles are a predefined set of flight software that executes in the RAM of the MDM. There is one bus profile per bus. The bus profiles are made up of processing frames that contain all the planned BC commands and RT responses. One processing frame equates to a data collection rate of 10 Hz. Therefore, telemetry that is gathered at only 1 Hz is pre-defined in the Input/Output Bus Profile to be collected once every 10 processing frames. More detail on processing frames can be found in the CDH training manual.

To ensure all MDMs are time synchronized, the BC sends out a "broadcast" time message at the beginning of every processing frame. MDMs that are RTs on the bus adjust their local time to that of the BC received time, and compensate for the travel time down the bus. ***If the computers get out of sync, two things can happen: 1) MDMs could be unknowingly putting the wrong data in the CVT resulting in incorrect data on PCS displays or 2) data collisions can occur, temporarily resulting in invalid data.***

CDH Software - Automated Fault Detection, Isolation, and Recovery

As described earlier, two types of automated FDIR software is available onboard. The first type, called Bus FDIR, is a common set of software located in the memory of all MDMs which acts as a BC. The Bus FDIR software automatically detects three things: channel failures, loss of bus communication from a RT, and loss of bus communication from the BC. ***Channel failures result in automatic channel switchover, which makes the redundant channel active.*** For example, if bus communication is using Channel A and this channel fails, bus FDIR automatically switches over communications so that Channel B is the active channel. ***The automatic switchover can be enabled or disabled by the crew or MCC-H.***

The second type of automated FDIR software is referred to as Remote Terminal (RT) FDIR. This type of FDIR handles MDM failures such as loss of communication, or total loss of the MDM. Generally, RT FDIR is dependent on the tier of the MDM (its redundancy). Therefore, for Tier 1 and 2 MDMs, the RT FDIR determines the type of failure and switches to a redundant MDM if appropriate. Due to the complex hardware/software redundancy of Tier 3, the Tier 3 RT FDIR typically varies by MDM. Processing states such as such as primary, secondary, backup, diagnostic, and startup are a critical part of the MDM switching. The switching process involves carefully transitioning effected MDMs through the applicable processing states for that MDM. A careful transition helps to minimize loss of system data and maximizes capture of troubleshooting data during the transition. ***For MDMs with warm backups, several seconds of system data can be lost. For MDMs with cold backups, up to approximately 2-3 minutes of system data can be lost.***

CDH Software - Summary

As depicted in Figure 2-15, a summary of key CDH software operations is as follows:

1. The C&C-1 MDM is the BC and is running its flight software from the MDM's RAM which includes a pre-established Input/Output Bus Profile for CB INT-1. Per the profile, it sends out a processing frame on the bus that includes a broadcast time message and a request for specific 10 Hz, 1Hz and 0.1 Hz data from the INT-1 MDM CVT

2. The INT-1 MDM updates its internal time to match with the C&C-1 time to avoid out of synchronization conditions

3. The requested CVT data is put on the CB INT-1 bus to the C&C-1 MDM

4. The C&C-1 MDM takes the data from the bus and puts it in its own CVT

5. The C&C-1 MDM, per the CB CT-4 Input/Output Bus Profile also running in its RAM, sends out a processing frame to the PCS which includes another broadcast time, a 1 Hz poll for any waiting commands, and new display data to the PCS at the rate of 10 Hz. Note that the PCS had already synchronized time to the MDM when it was connected and has drifted from the time. It only resynchronizes each time it is connected to a bus.

6. The PCS per C&C MDM request, the PCS puts its command on the bus at the maximum rate of one command/sec/PCS

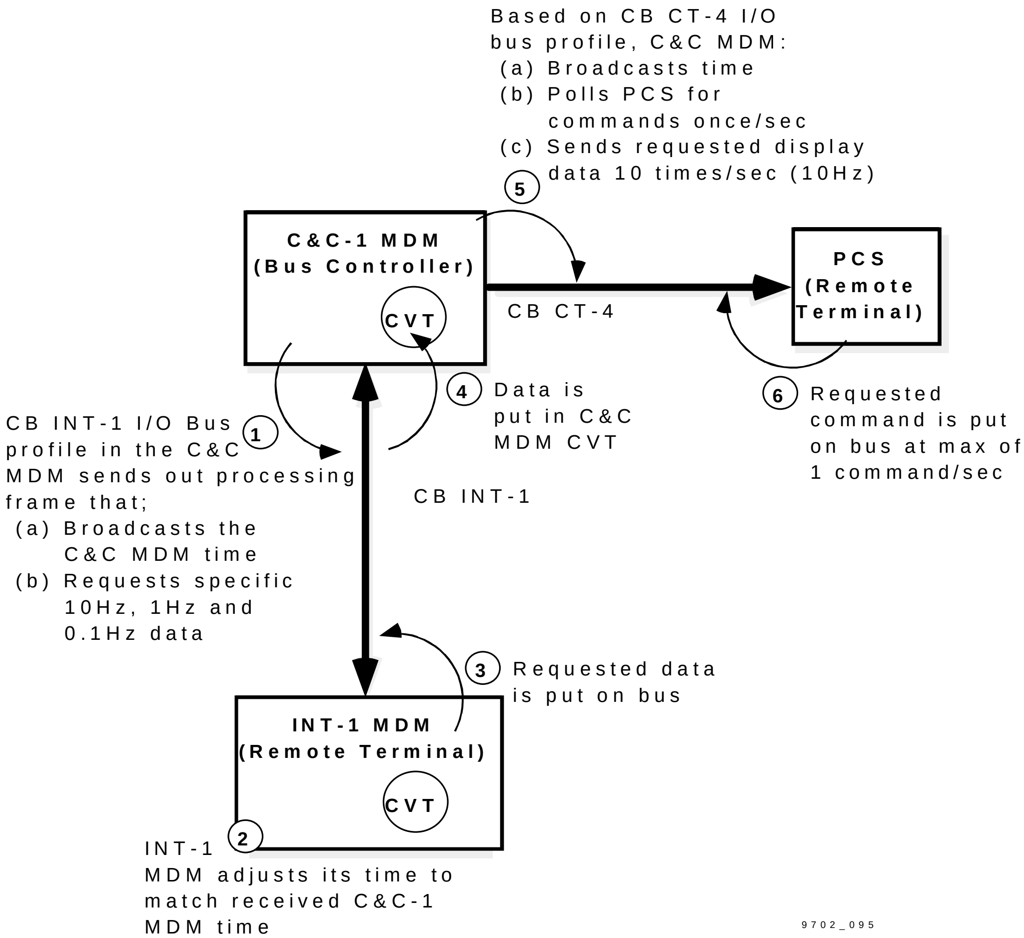


Figure 2-15. Summary of key CDH software operations

Although it is not depicted in Figure 2-15, after the PCS command is put on the bus, positive and negative command response messages are sent to the PCS that sent the command as the command progresses through the CDH system. Recall that since all buses are operating nominally in this scenario, it does not matter which specific control bus the PCS is connected to. Should bus or MDM failures be detected at any point in this scenario, the PCS may need to be moved to another port. Also, automated bus and/or MDM FDIR tries to recover from the failure.

While the key aspects of the CDH software have been described, there are many other aspects to this software such as data dumps, data loads, extended data dumps, file transfers, application software configuration, Power on Self-Tests (POSTs), and Built-In Tests (BITs). All of these capabilities significantly affect operations. Descriptions of these topics can be found in the CDH Training Manual.

2.6.1.4 *CDH Interfaces to Other U.S. Systems*

The interfaces between CDH, the U.S. Electrical system, the U.S. Thermal system, and the communication system are designed to maximize redundancy and minimize cascading failures.

At 8A, there are two independent solar array power channels. These channels provide power to CDH based on MDM redundancy. Typically, the first instance of MDMs, such as C&C-1, INT-1 and PMCU-1 are all powered by one power channel and redundant MDMs (such as C&C-2, INT-2 and PMCU-2) are powered by the other channel. Power channel sources for Tier 3 MDMs are based on the unique redundancy of those MDMs. Additionally, each MDM has its own software-controlled power switch, called a Remote Power Controller (RPC), that allows operators to power the MDM on or off. Since an unpowered MDM cannot close its own power switch, the switch is controlled by another MDM.

Thermal interfaces for CDH components vary whether the component is outside or inside the habitable volume. Most MDMs located outside have simple strip heaters within the box as well as separate baseplate survival heaters located outside the box. The strip heaters are considered part of the MDM and are controlled by the MDM containing the heater. The baseplate survival heaters are powered by a different power channel than the MDM they are heating. They are also controlled by a separate MDM. The Node 1 MDMs located externally on the Node 1 shell are unique since, in addition to survival heaters, they have radiators attached to them. In certain Station attitudes, the Node 1 MDMs require cooling which is provided by these radiators. As described in 2.6.1.1, the lab has two internal thermal cooling loops: a moderate temperature loop and a low temperature loop. All MDMs located inside the lab are mounted on coldplates which are cooled by the moderate temperature loop. Should the moderate temperature loop pump fail, the two thermal loops can be interconnected to maintain cooling to the MDMs. Therefore, thermal redundancy is provided to the internally located MDMs which are all actively cooled by the same moderate temperature loops. Both the electrical and thermal interfaces to MDM's are depicted in Figure 2-16.

The majority of the interfaces to the communications system are through the C&C MDMs. Data and commands are exchanged over the CB CT buses. The C&T system receives/sends 1553 information to the C&C MDM and handles the processing of the data for RF transmission to the ground within its own components. The ZOE recorder provides another interface between the two systems. This C&T component records key Station data on a continuous 107-minute cycle and stores the information in the C&C MDM. After a ZOE, MCC-H can request that the recorded data be dumped to the ground for analysis.

2.6.1.5 *CDH Assembly*

The final aspect of CDH is the buildup of the system. As seen in Figure 2-12, the majority of the CDH components, including the C&C MDMs are located in the lab. This hardware is not available prior to the lab flight on 5A. Therefore, the Station needs an alternative computer system to handle the Station prior to lab activation. This system is called the "Early CDH" system and is based on the Node 1 MDMs. From 2A until 5A activation of the C&C MDMs, the Node 1 MDMs control the U.S. CDH and interface directly with the Russian computers. The software in the node MDMs is a minimum set of software required to get to 5A activation. However, if all three C&C MDMs fail, the node MDMs can take over control of the U.S. CDH with very limited capabilities. Another key aspect of the early CDH is the interface to the Orbiter Interface Unit (OIU) which acts primarily as a RT to the Node 1 MDM. More details on Early CDH and the OIU can be found in the CDH Training Manual Appendices.

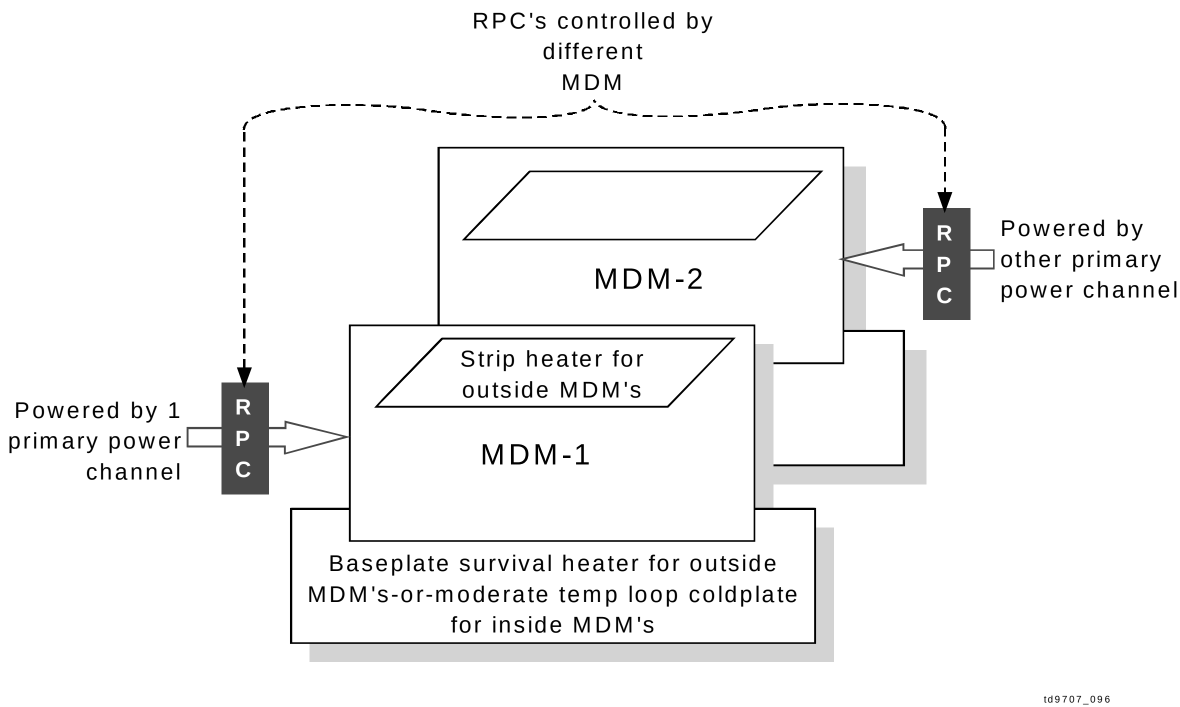


Figure 2-16. Conceptual depiction of electrical and thermal interfaces to CDH

2.6.2 Russian Computer System

2.6.2.1 *OCCS Architecture*

The Russian OCCS and U.S. CDH computer system architectures are very similar in that both systems can be conceptually viewed as having three tiers of computers. However, the Russian segment does not officially refer to them as tiers. Additionally, while the U.S. CDH system uses a highly distributed approach for the lower tier computers, the Russian OCCS uses a module-based approach. Figure 2-17 depicts a functional drawing of the OCCS. Notice that the OCCS has a central computer located in the SM which connects to a two-tier computer system within the SM and a separate computer system with the FGB. The modular approach allows for the FGB and SM computer systems to be generally self-sufficient. The U.S. CDH, due to its integrated nature, does not have the capability for independent computer systems.

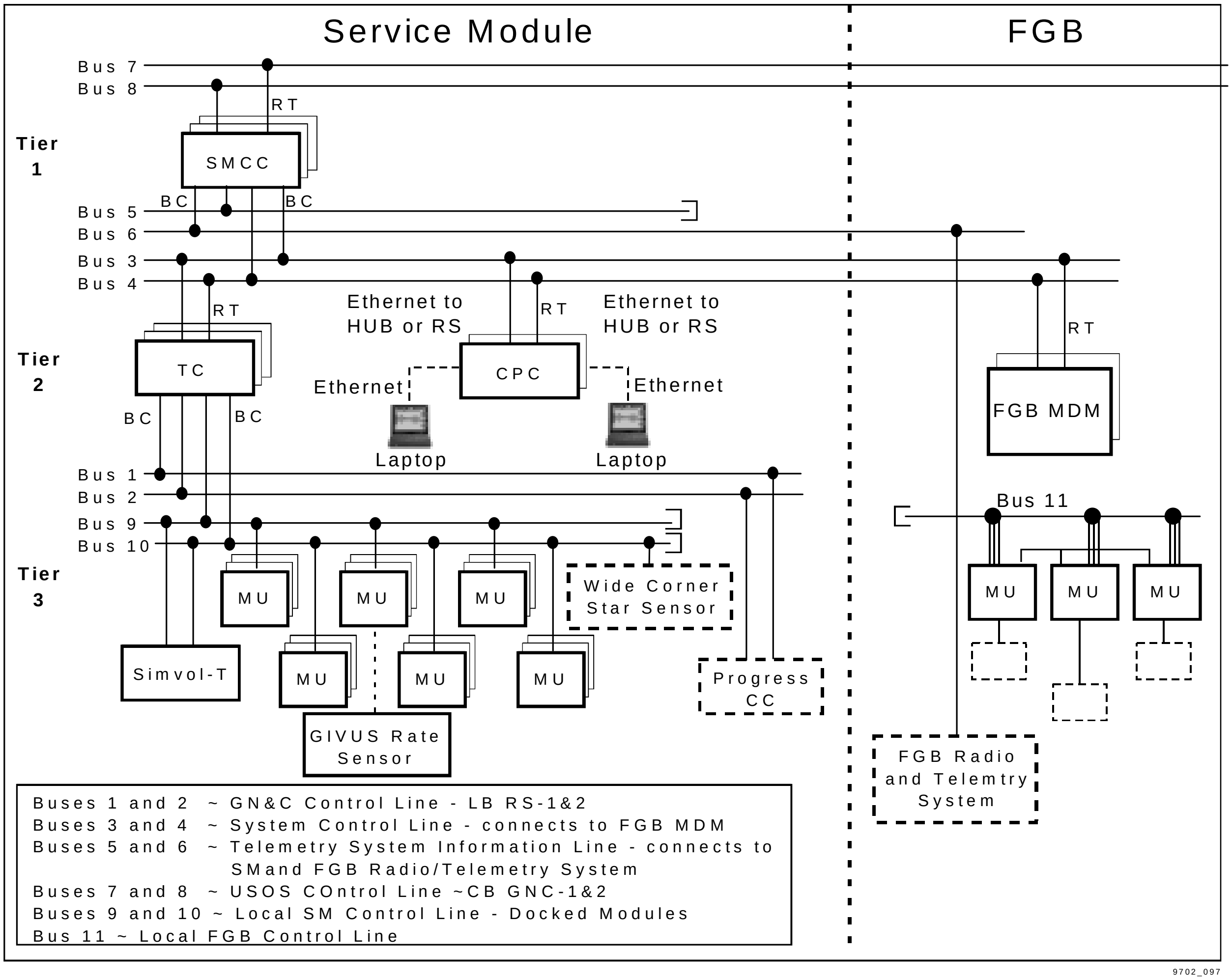


Figure 2-17. Functional drawing of OCCS

At 8A, the OCCS has approximately 33 computers and is a logical update from the Mir OCCS, with the major change being an increase in electronic control of the Russian modules through computer displays. The SM Central Computer (SMCC) is similar to the Tier 1 U.S. C&C MDM as it also provides the interface to the crews and controllers. As identified in Table 2-2, crewmembers interface to the SMCC via the fixed CPC or via Russian laptops. Notice from Figure 2-17 that the Russian laptops use an ethernet cable to connect to the CPC which then connects to the SMCC via a standard data bus. ***As in the U.S. CDH, crews and MCC-M controllers are only able to access data that has been passed to the SMCC.*** Russian computers communicate over databases which use the Russian GOST 26765.52-87. This protocol is the Russian version of MIL-STD 1553B and is essentially the same protocol.

The two-tiered SM computer system is similar to the Tier 2 and Tier 3 computers in the U.S. CDH. The Tier 2 SM computers, referred to as terminal computers, contain module-specific application software and interface to the SMCC as well as to Tier 3 computers called matching units. The matching units interface directly to Russian sensors and effectors.

The FGB computer system generally follows a two-tiered hierarchy as well. The Tier 2 computers are the U.S.- provided FGB MDMs and the Tier 3 computers are matching units.

Figure 2-18 provides a spatial drawing of the Russian Computer System. From Figures 2-17 and 2-18 it is clear that beyond Tier 1, the Russian computer system has more redundancy than the U.S. CDH. ***There are three redundant SM central computers, which take in the same data, process it with identical software, and utilize a voting scheme on the output to ensure data integrity much like shuttle GPCs. There are also three redundant terminal computers that use a similar voting scheme as the SMCCs. The matching units are also triple redundant.***

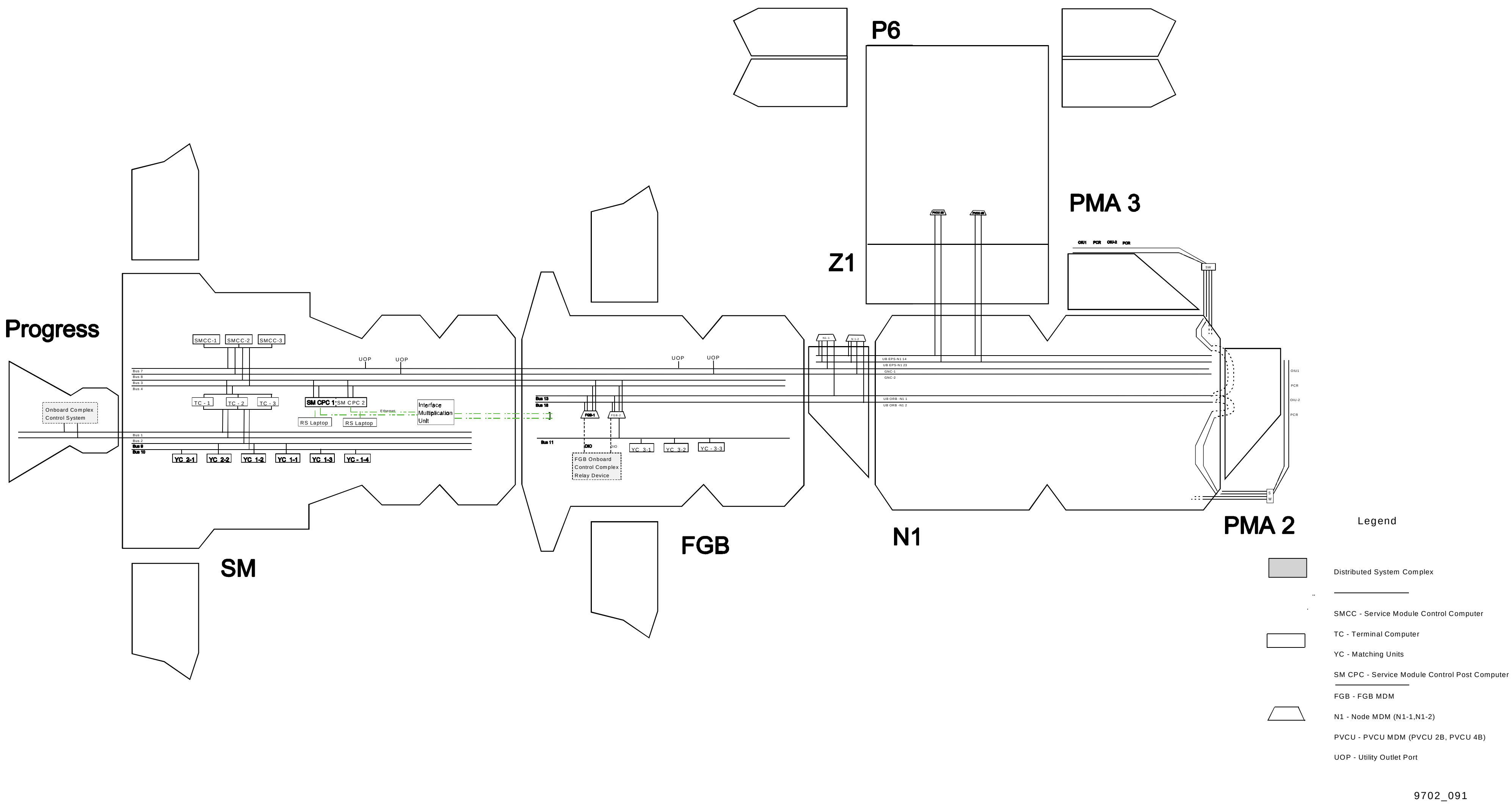


Figure 2-18. Russian segment computer systems at 8A

2.6.2.2 *OCCS Hardware - TBD*

2.6.2.3 *OCCS Software - TBD*

2.6.2.4 *OCCS Interfaces to Other Russian Systems - TBD*

2.6.3 Japanese Computer System - TBD

2.6.4 European Computer System - TBD

2.7 Multisegment Data Exchange

As described earlier, there are multisegment data buses that are used to communicate between partner computer systems. All IP computer systems exchange key share health and status data. Additionally, electronic C&W information is exchanged between all partners and is therefore available to all partner crew interface computers for display. All information exchange between segments is done using the MIL-STD 1553B protocol and a pre-established Input/Output Bus Profile for the specific multisegment bus.

At 8A, the only partner interface is the one between the Russian OCCS and the U.S. CDH. ***As seen in Figures 2-10, 2-12, 2-17 and 2-18, there are two multisegment buses between the C&C MDMs and the SMCCs. They are referred to as CB GNC-1 and CB GNC-2 in the CDH system and Bus 7 and Bus 8 in OCCS. These buses exchange top level health and status information for all systems, including Station moding commands. All data exchanged is available for display.*** The GNC system on Station is unique because it is the only system to exchange information directly between Tier 2 Russian and computers. This is because the Russian and U.S. GNC systems operate so integrally to each other and must coordinate overall Station GNC operations. ***The buses between the U.S. GNC MDMs and the SM Terminal Computers are called LB RS-BUS 1 and LB RS-BUS 2. Specific data exchanged includes state vector, attitude, and mass properties. If the data is moved up to the Tier 1 computers, then this data is also available for display.*** Detailed descriptions of this GNC multisegment data can be found in the GNC Training Manual.

A unique aspect to Russian and U.S. computer system interfaces is associated with the Russian and U.S. communications systems. The Russian communication system provides for transmission of data and commands between the Russian segment computer system and MCC-M. The U.S. communication system provides for transmission of data and commands between the C&C MDM and MCC-H. However, ***each partner segment can also send commands and receive data from its computer system via the partner's control center and communication system. For example, MCC-H can send a command to MCC-M which is transmitted over the Russian communication system to the Russian computer system and to the C&C MDM using the multisegment buses.*** More detail on this capability is provided in the Communications Training Manual.